Introduction

The spatial resolution of various instruments and missions is a very important thing for us to consider in the course of our work. We're using data that come from several different surveys, with different spatial resolution. This is most vividly seen by a comparison of WISE channel 1 and 2 with Spitzer IRAC channel 1 and 2 because the wavelengths are very nearly the same (and the telescopes are different), but it will matter a lot in particular for the WISE, AKARI, PACS, MSX, SCUBA, and IRAS data.

MY GOALS for you in doing this are to (1) develop a sense of what spatial resolution means and how it changes between telescopes, e.g., WISE vs. Spitzer vs. 2MASS vs. Herschel resolution; and (2) understand what the challenges will be for us in matching across wavelengths. (3) I also think we should, anticipating comments from the referees, be able to add a column to our big table with the resolution of each dataset.

Ancillary goals (e.g., you can't do this worksheet without also accomplishing these): (1) get used to working with FITS files, manipulating stretches, etc.; (2) identifying objects in and measuring distances on FITS files; (3) learn how to use Finder Chart (and other IRSA tools), ds9, and Skyview as resources to be used down the road on whatever you find yourself doing next.

For a general introduction, please start with the main text already on the wiki for Resolution. Please also look at the examples lower on that page, but you don't need to actually do the one that suggests that you go download data, etc. The skills you might have gained from that specific example will be stuff that we do as part of our project.

We will be using IRSA's Finder Chart and IRSA Viewer (which is a more generic version, accessing more data at IRSA) to retrieve images, but we will also use Goddard's Skyview to retrieve larger FITS images. You need a way to view and interact with FITS files (see FITS explanation below). Finder Chart (and IRSA Viewer) allow you to interact directly with the FITS files. You could also use ds9, which you can download here: DS9. Also, ds9 was the topic of a tutorial in NITARP tutorials.

Basics and other things to note

Background information

If you need a refresher on mosaics, see What is a mosaic and why should I care?

If you need a refresher on angular measures on the sky, see this site from LCOGT.

A bit more information on FITS format is elsewhere on the wiki. The most important thing about FITS format vs. other image formats is that JPGs (and for that matter GIFs or PNGs) are "lossy compressed" files, which means that images in those formats actually LOSE INFORMATION, particularly in comparison to the FITS file. JPGs are just fine for images you take of your kids with digital cameras - you rarely ever see evidence of the loss of information. (As an aside - you might see evidence of it if you take a picture of something with high contrast, or a sharp edge somewhere in the image. If you look at the jpeg up close, you will see 'ringing' of the sharp edge, which looks kind of like blurring. The Wikipedia page on lossy compression linked above has an example of loss of information with JPGs.)

So, what this means is: **any time you are doing science**, whether that is using your eye to see small details in the image, or measuring distances, or doing photometry, **you always want to be using the FITS file**, *never* a JPG, PNG, or GIF.

When you download the FITS files (from anywhere), the default filename is very likely related to the process id on the server, e.g., it won't mean anything to you 10 minutes after you download it. In the process of downloading images, you should rename the images straightaway to be something that you can understand and remember later on.

We will largely be using Finder Chart, IRSA Viewer, ds9 and Goddard's Skyview. Detailed documentation for all of these is available at their respective websites. I've made videos for many of these tools, either in my feed or the IRSA YouTube feed.

Skyview

For Skyview, we will use the full Query form, not Quick View and not Non-Astronomer's page.

Skyview pulls together some huge number of surveys in one place and makes them accessible to you in an easy, fast interface. It will resample and regrid and remosaic all sorts of surveys for you, from gamma rays to the radio. (That is, as we will see, both a strength and a weakness.) I don't know exactly if it conserves flux (e.g., if one can still do photometry off of the mosaics it provides); I would err on the side of caution and NOT use this for anything other than morphology, e.g., do science by eye with the mosaics, and you can use them for distance measurements on the images, but don't do photometry on these mosaics.

Skyview will always spawn the same second window for the results. The first time you call it, it will spawn a second browser tab or window (depending on your local configuration), and then, if you don't close that second tab or window explicitly, the next search results will go into that same window, even if it's hidden below where you are currently working. *It will make it seem as if nothing has happened when you submit your search request.*

In Skyview, you can ask for more than one survey at the same time, but it uses the same 'common options' you specify on the query page. To select more than one survey that are not adjacent in the list, hold down the command key while clicking. (That is, at least, on a mac. Your mileage may vary.)

Skyview will allow you to download both the JPG and the FITS file (click on "FITS" to download it). You want FITS, as per above. :)

If, in the future, you need to find Skyview, you will probably need to google "Goddard Skyview" as there is at least one other software package called Skyview (including one at IPAC that is mentioned more than once in the wiki) that does something else entirely.

FITS Viewers: ds9

You need software capable of reading FITS files. There is some information on using a variety of packages here.

As our first but certainly not last example of "astronomers using whatever software you are most familiar with to do the job", you are more than welcome to use your own favorite FITS viewer (if yours has an easy way to measure distances).

You might as well start to get comfortable with using ds9. It's free, and available for just about any platform. There are at least 2 tutorials on using ds9 developed by NITARP students on the wiki for doing some specific things - search in the wiki on ds9 - and more from the rest of the web, including some listed at the bottom of this page. Also, ds9 was the topic of a tutorial in NITARP tutorials.

When clicking around on ds9 images, you may occasionally leave behind a green circle; this is a "region", and they are ultimately very helpful, but when learning things, they can be very annoying. To make accidental regions go away, pick the region, and hit backspace or delete on your keyboard or from the top regions menu.

For this worksheet, you need to be able to measure distances. Measuring distances in ds9 is basically creating a special 'region' that is a ruler, so you may find it clunky. From the menus on the top, select Region/Shape/Ruler. Click on one end of what you want to measure, then move to the other end and click again (or click-and-drag; you may need to experiment to see what your system wants). A line with arrows will be drawn connecting the two, along with the distance in text and dotted lines completing the triangle. By default, the distance will be in physical units (pixels of the image you are viewing), but by accessing the region's Get Information panel (top menu: Region/Get information; buttons in the middle of the ds9 screen: Region/Information), you can change both the endpoints and (more usefully) distance units to WCS so that the units will be in degrees, or minutes, or seconds.

In recent years, we have had some skittishness from Windows machines when running ds9. It may very well be that you will have an easier time using IRSA tools (see next) than ds9, although ds9 is (for the moment) ultimately more powerful.

ds9 Tutorials from Babar from 2012:

- Video 1: How to load and view and image in ds9
- Video 2: How to read information about your image in the information panel of ds9

ds9 Tutorials from the official NITARP tutorial (Jan 2013):

- Part 1: ds9 overview - what is ds9, etc (10.5 min)
- Part 2: the first half of the ds9 demo - getting it started, basics of usage (19 min)
- Part 3: the second half of the ds9 demo - more advanced tips and tricks (25 min)

Tutorial from Milton Johnson from 2016:

- Starting ds9 from the command line in Windows (10 min)

FITS Viewers: Finder Chart (and IRSA Viewer)

Finder Chart and IRSA Viewer both use software that is called "Firefly", and both tools have a similar look-and-feel. Finder Chart was originally designed to create finder charts for use at a telescope, but it has evolved into one of IRSA's most popular tools. It provides images from up to 5 surveys in up to 21 bands, and allows simultaneous searches of the corresponding catalogs. IRSA Viewer is a more generic version of Finder Chart, providing the FITS viewer and one-by-one image retrieval and catalog searches.

In both cases, the search capability is integrated with the FITS viewer capability. (In Skyview, these capabilities are not integrated.) When Finder Chart or IRSA Viewer give you images as a result of a search, you are looking at (and interacting with) the original FITS files. There is a toolbox on the top of both tools that can be used with the images. You can change color stretches and color tables, you can leave markers on the image, you can read in catalogs (and ds9 regions files), etc. In Finder Chart, by default, all the images are

locked together, so what you do to one image (zoom, etc.), happens to all of them. (To unlock them, click on the lock icon in the image toolbox.) (Just for completeness, in IRSA Viewer, there is no *a priori* guarantee that the images that are loaded are of the same patch of sky, so they are by default NOT locked.)

You can also measure distances in Finder Chart (or IRSA Viewer). For this Resolution worksheet, you need to be able to measure distances. Click on the ruler icon, then click and drag in the image to measure a distance. Click on the layers icon to bring up a pop-up that specifies the units for the length of the vector you have drawn in degrees, arcminutes, or arcseconds.

Images retrieved via Finder Chart or IRSA Viewer are coming from the original archives corresponding to each survey, so they are basically guaranteed to be unresampled images, so they are OK for doing detailed science, including photometry. There is an excruciatingly simple way of guesstimating photometry within Finder Chart or IRSA Viewer, but it's nowhere near accurate enough for scientific analysis.

Finder Chart and IRSA Viewer also let you retrieve and overlay catalogs. Skyview doesn't let you do that at all. On the other hand, Finder Chart and IRSA Viewer are limited to the tiles currently publicly stored here at IRSA; most of the time, you won't notice the tiles, but the 2MASS tiles are crazy small (that's a technical term) so if you ask for any reasonable amount of sky at all, you'll get a tiny 2MASS image surrounded by black, blank sky. In order to get big 2MASS images, you need to get them some other way, like from Skyview.

Click on "prepare download" to get the FITS (or the pngs, or a pdf, or the html for that matter).

The IRSA YouTube Feed has playlists on both Finder Chart and IRSA Viewer.

Notes on Distances

You can also measure distances by hand by comparing pixel coordinates. Note that as you move your mouse around on the image in any of these FITS viewers, it will give you an updated readout of the RA and Dec near the top. You can change this from hh:mm:ss ddd:mm:ss format to decimal degrees for both RA and Dec -- for ds9, you do this by picking from the "wcs" menu at the top, either 'degrees' or 'sexagesimal'. Make a note of the RA/Dec from which you want to measure a distance, and the RA/Dec of the end point of the distance measure.

No matter how, exactly, you do this, WATCH YOUR UNITS. **RA by default is in hours, not degrees. Dec by default IS in degrees.** How do you convert between hours and degrees? (Hint: there are 24 hours of RA ...and 360 degrees.)

Technically, to be absolutely correct, because you are calculating distances on a sphere, in order to do this, you need to do spherical trigonometry. This matters because the angle subtended by 1 hour of RA on the celestial equator is much larger than that subtended by 1 hour of RA near the celestial pole. For quick and dirty purposes, it should be mostly fine to simply subtract the RA and Dec to get a reasonable estimate of the distance BUT WATCH YOUR UNITS because RA by default is in hours:min of time:sec of time, not deg:arcmin:arcsec.

The spherical trig does make a difference, though. See this excerpt from someone's class notes with some really nice graphics and explanations of why you need to do this, and how to do it right. (hint: For the distances we'll consider here, you need a cosine of the declination. I won't make you do the full spherical trig in most cases.) For the ambitious, anticipating skills you'll need downstream from this worksheet, try programming a spreadsheet to do this for you, given two RA/Dec position pairs. **NB: Be sure to watch your units on the Dec-- some cosine functions want radians, and some take degrees.** (Bonus: how much of a difference in Ceph C does it make if you leave out the cos(dec) term? Is that going to get worse or better if we move closer to the north celestial pole?)

Getting started: what sizes do we expect?

Googling to get what you need is expected and ok!

Let's start by calibrating our expectations by thinking about the sizes of things in arcseconds (or arcminutes or degrees) with which we are more familiar before launching into measuring things on the FITS images.

- **Q1.1:** What approximate angular size is the Moon?
- **Q1.2:** What approximate angular size is Jupiter?
- **Q1.3:** What approximate angular size is Proxima Centauri? It is a M5.5 Ve, and so its radius is about 0.15 Rsun. Its parallax is 774.25 milliarcsec.
- **Q1.4:** Put our Sun, with a Kuiper Belt, at the distance of Proxima Centauri. What angular size would the Sun be? The Kuiper Belt? In reality, the circumstellar disk surface brightness is much, much fainter than the central star, but for purposes of this example, let's ignore that. Take the solar radius as 7e5 km and the KB as 6e9 km.
- **Q1.5:** The disk around beta Pictoris is about 1650 AU in radius. (Beta Pic's parallax is 51.44 mas.) What angular size would that be? (Again, though, the brightnesses are so different, in order to see the disk at all, you have to block out the brightness of the central star and integrate for a long time.)
- **Q1.6:** M8 is about 1200 pc away. Put a star/disk system just like Beta Pictoris in M8. What size would it be, ignoring issues of surface brightness and contrast with the star?

THE POINT OF DOING THIS: will we see any disks or rings around our stars using our data? You may need the resolution information from the below to answer this. :) Having gotten the answer to this, you will be met with a Paddington Bear-style "hard stare" if I hear you telling anyone that the "rings" in the MIPS-24 data are rings of dust around those stars.